Hot/Cold Effective Noise Temperature Measurements

By William E. Dumke, November 20, 1994 for Swagur Enterprises

1.0 Table of Contents

2.0 Effective Noise Temperature/Noise Figure Derivations

Based on VLA Electronics Memorandum No. 197, Modem T1 Compression, Early Measurements, Optimization of Channel Selection, and Recommendations, W.E. Dumke, October 1980, The National Radio Astronomy Observatory, Socorro, New Mexico, Very Large Array Program, Appendix B

2.1 Definitions of Terms

Pn = available noise power in watts

k = Boltzmann's constant = 1.38×10^{-23} Joules/^{o}K

T = absolute temperature in ^{o}K

B = bandwidth in Hertz

Te=effective input noise temperature of system

N = noise power ratio

F = noise figure in dB $F = 10 \cdot \log(N)$ dB

G = gain of device

2.2 Definition of Noise figure

$P_n = k \cdot T \cdot B$ for a linear, passive network

Let N_i = noise input to device from terminated load at temperature 290 K

$$N_i = k \cdot 290 \cdot B$$

Let No = noise output of device from terminated load at 290 K and effective input noise temperature

$$N_o = G \cdot k \cdot B \cdot (290 + Te)$$

$$N = \frac{N_o}{G \cdot N_i}$$ from IRE definition of noise factor

$$N = \frac{G \cdot k \cdot B \cdot (290 + T_e)}{G \cdot k \cdot B \cdot 290}$$ Therefore, $$N = 1 + \frac{T_e}{290}$$

$$F = 10 \cdot \log\left(\frac{1 + T_e}{290}\right) \text{ dB}$$

2.3 Noise Figure Measurement with Hot and Cold Load

Let Y_{hc} = Y-factor (output noise power ratio) for hot and cold load meaurement

$$Y_{hc} = \frac{G \cdot (T_e + 290)}{G \cdot (T_e + 77)} \qquad \text{Therefore,} \qquad T_e = \frac{290 - Y_{hc} \cdot 77}{Y_{hc} - 1} \quad {}^{o}K$$

with $F = 10 \cdot \log\left(1 + \frac{T_e}{290}\right)$ dB

2.4 Noise Figure Measurement of an Individual Amplifier

Based on Noise Performance Factors in Communication Systems, by W.W. Mumford and E. H. Scheibe, Horizon house, 1968, page 48

Let N = noise factor of entire system

Let N_1 = noise factor of first amplifier

Let G_1 = power gain ratio of first amplifier

Let N2 = noise factor of rest of system

Then $N = N_1 + \frac{N_2 - 1}{G_1}$

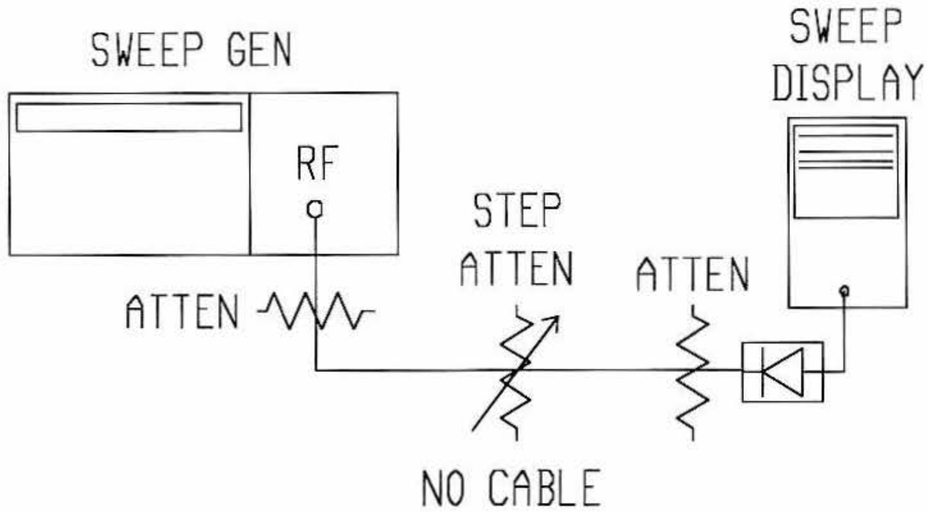
N and N2 can be measured as before. And the gain of the first stage can be measured using a signal source and power meter.

To calculate the noise factor of the first stage, $N_1 = N - \frac{N_2 - 1}{G_1}$

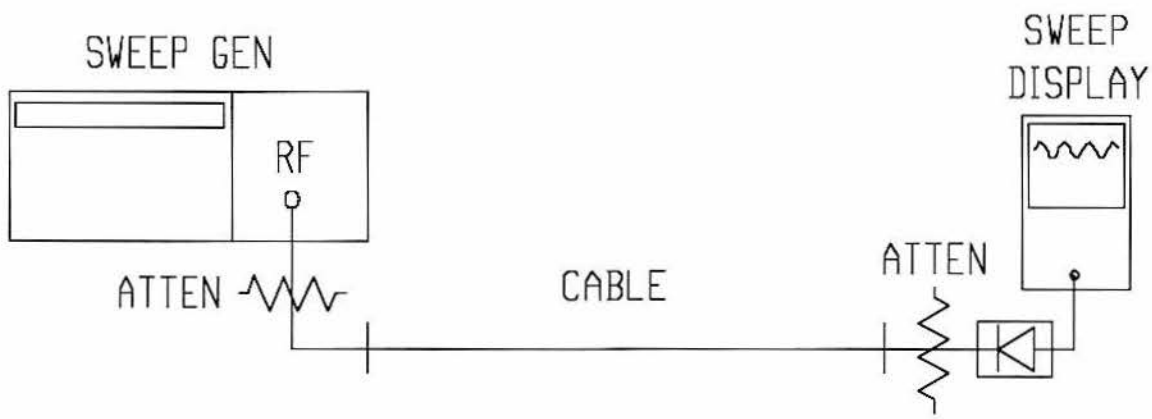
And, $F_1 = 10 \cdot \log(N_1)$ dB

3.0 Calibration

3.1 Sweep Display Calibration for Attenuation

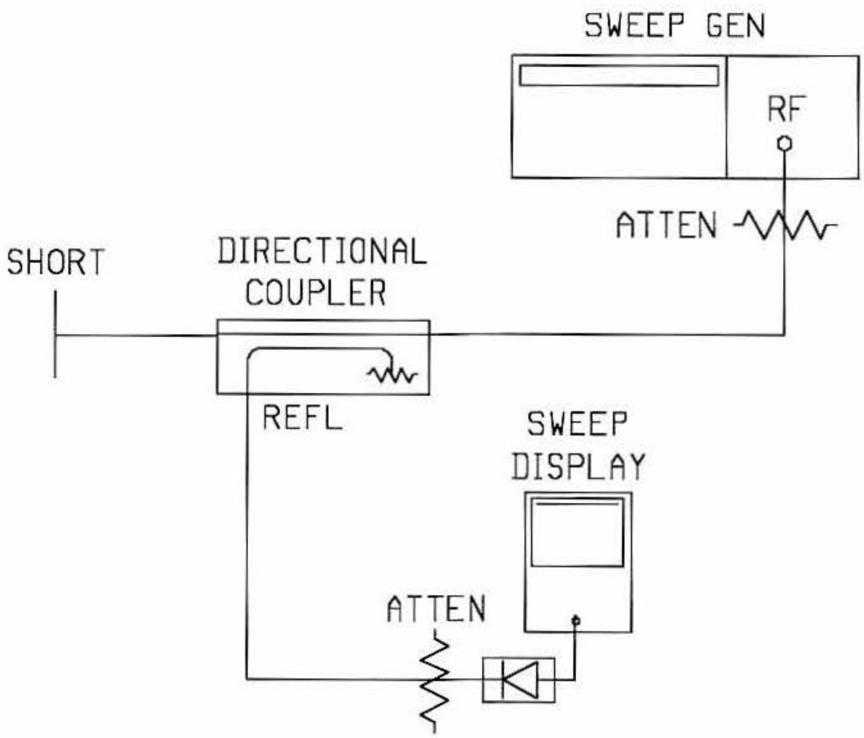


3.2 Coaxial Cable Attenuation

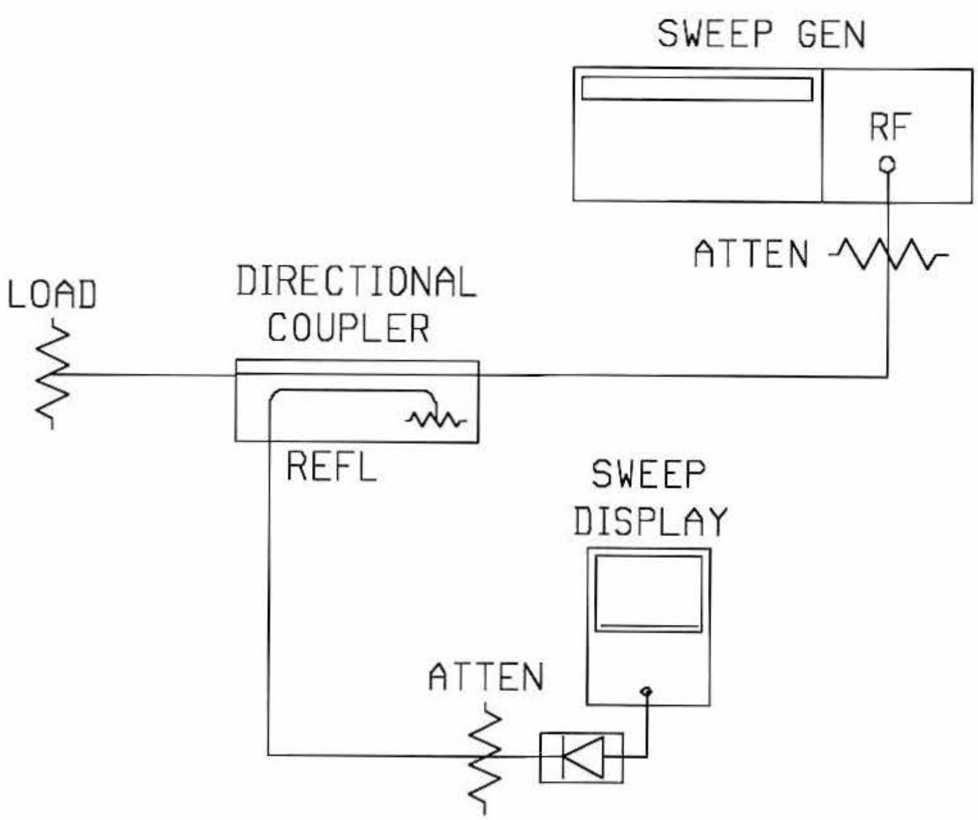


3.3 Sweep Display Calibration for Return Loss

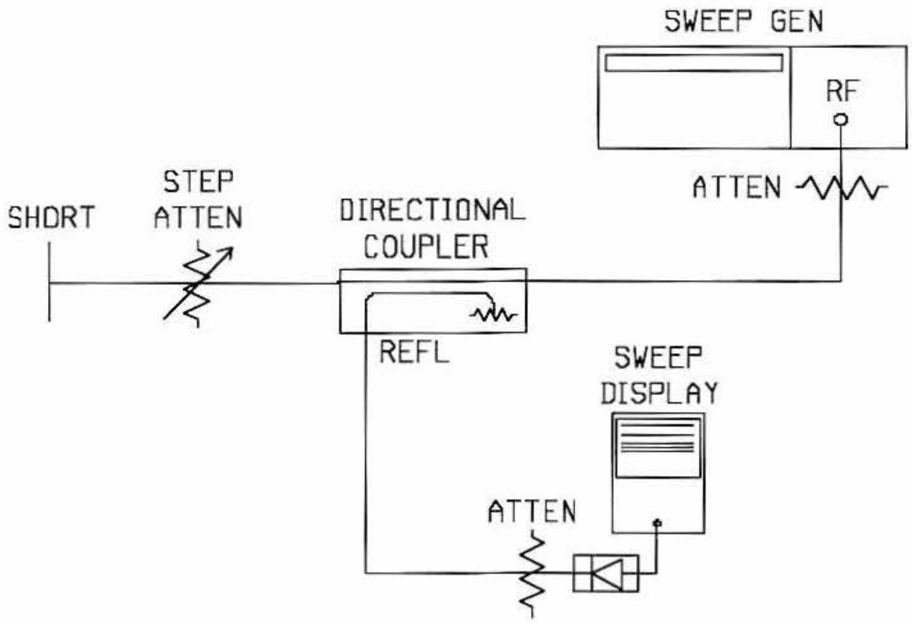
3.31 Short Circuit



3.32 Matched Load

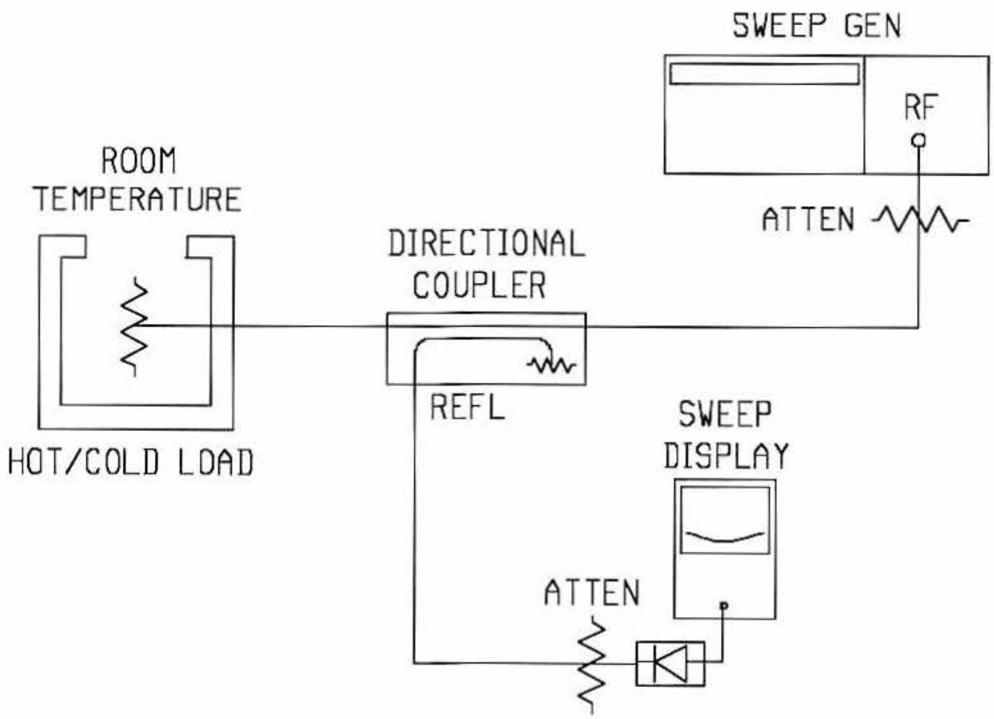


3.33 Attenuator with Short Circuit

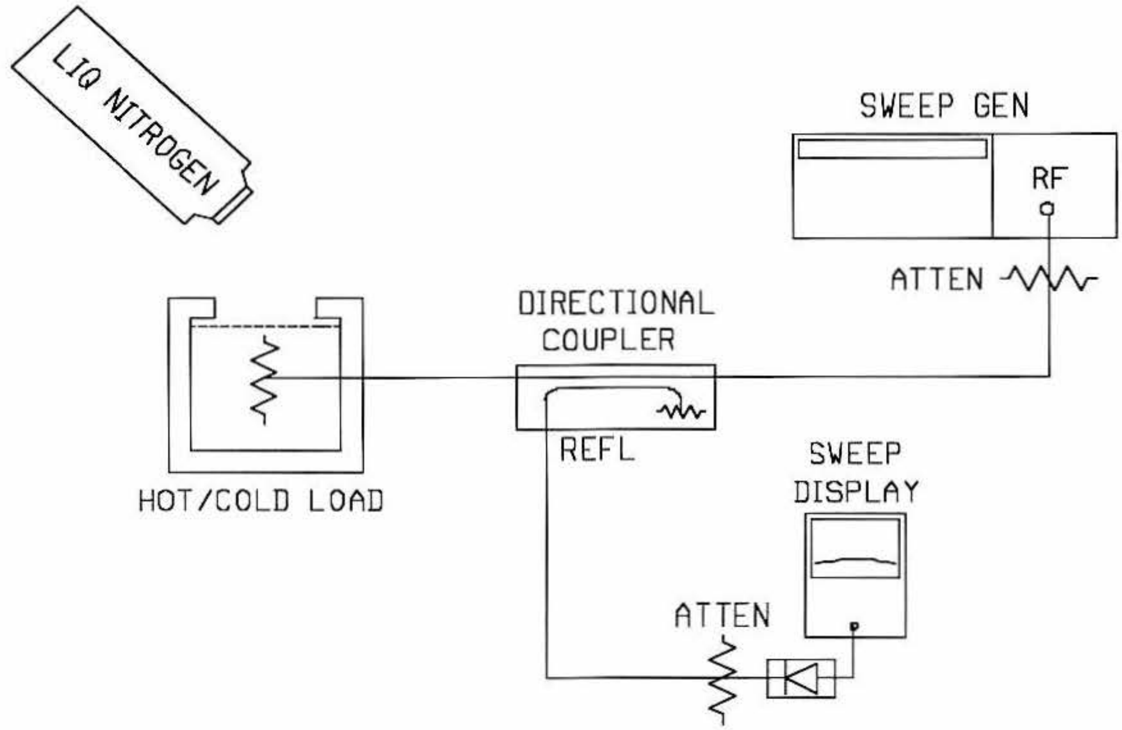


3.4 Swept Return Loss of Hot/Cold Load

3.41 Hot



3.42 Cold



4.0 Hot and Cold Load Noise Measurement Using Liquid Nitrogen

4.1 Definition of Terms

P_h = output noise power with hot load (room temperature approximately 290 ^oK)

P_c = output noise power with cold load (liquid nitrogen approximately 77 ^oK)

Let T_h = hot load temperature in degrees Kelvin, ^oK

Let T_c = cold load temperature in degrees Kelvin, ^oK

4.2 Temperature Conversions

All temperaures in the formulas are in degrees Kelvin, ^oK, unless otherwise noted.

To convert from Fahrenheit to Kelvin, Let $i := 1 .. 4$ (4 measurements total)

$T_{h_i} =$

69.2
70.3
70.2
70.4

Let T_{h_i} = (values above) ^{o}F, the room temperature (the hot load)

$$T_{h_i} := \frac{5}{9}\cdot\left(T_{h_i} - 32\right) + 273.15$$

T_{h_i}

293.817
294.428
294.372
294.483

Therefore, T_{h_i} = (values above) ^{o}K

From the Handbook of Chemistry and Physics, 50th Edition, page D-131, the boiling point of Nitrogen is given as -195.8 ^{o}C.

To convert from Centigrade to Kelvin,

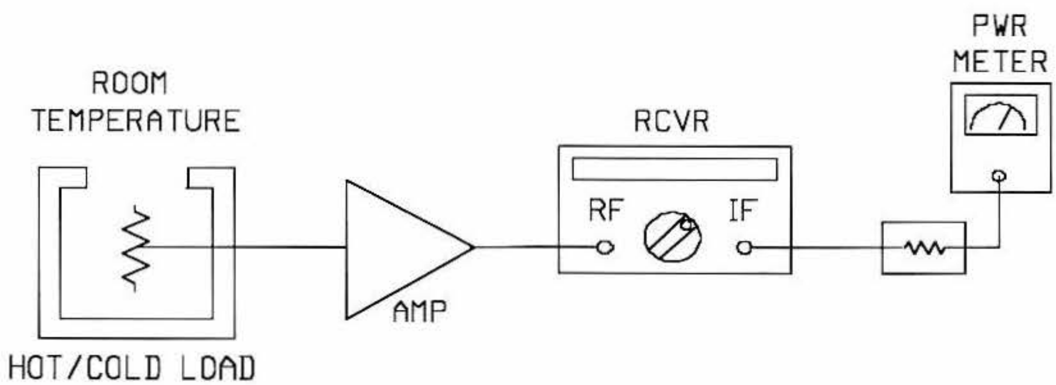
Let $T_c := -195.8$ ^{o}C, the boiling point of Nitrogen (the cold load)

$T_c := T_c + 273.15$ Therefore, the boiling point of Nitrogen $T_c = 77.35$ ^{o}K

4.3 Hot and Cold Noise Measurement Using Liquid Nitrogen

4.31 Hot (Room Temperature)

Turn on the equipment and let the room and equipment temperatures stabilize.



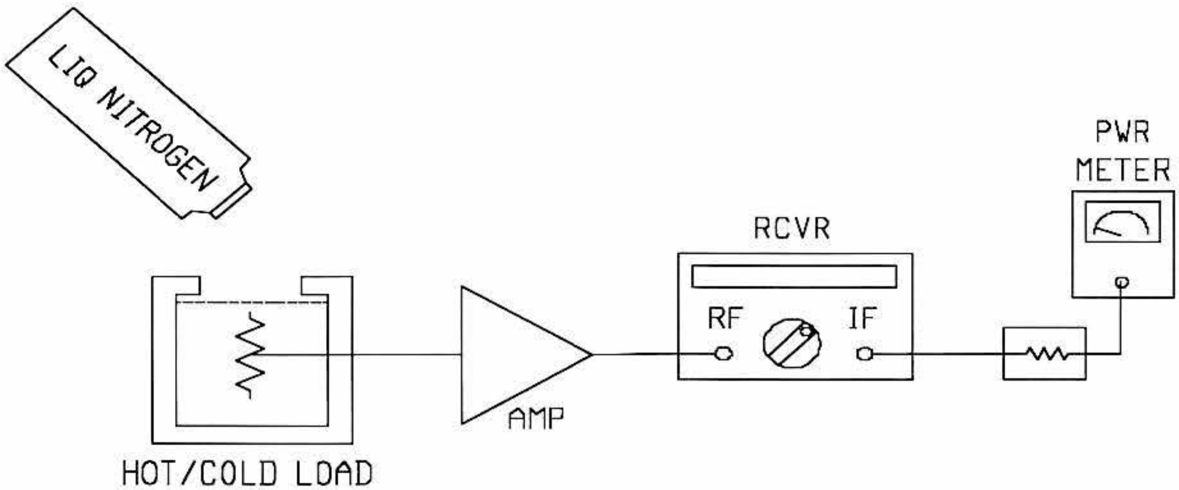
Measure the output power (or the rms voltage) at hot, room temperature.

V_{h_i}

Measured Values:	0.076	Vrms
	0.085	
	0.080	
	0.086	

4.32 Cold (Liquid Nitrogen)

Add the liquid Nitrogen and wait until the output power stabilizes.



Measure the output power (or the rms voltage) at cold, liquid Nitrogen.

V_{c_i}

Measured Values:	0.051	Vrms
	0.0555	
	0.0515	
	0.0565	

The Y - Factor, $Y_{hc_i} = \dfrac{\left(V_{h_i}\right)^2}{\left(V_{c_i}\right)^2}$ yields

Y_{hc_i}
2.221
2.346
2.413
2.317

The effective noise temperature, $T_{e_i} := \dfrac{T_{h_i} - Y_{hc_i} \cdot T_c}{Y_{hc_i} - 1}$ yields

T_{e_i}
99.982
83.975
76.235
87.537

^oK

In the equations you presented to me in the QBASIC program,

The noise figure, $F_i = 10 \cdot \log\left(1 + \dfrac{T_{e_i}}{T_{h_i}}\right)$ yields

F_i
1.272
1.09
1
1.13

dB

Which are exactly the same results you presented to me.

However, **"The *standard noise temperature*, To, for noise measurements is 290^{0}K."**

From Noise Performance Factors in Communication Systems, by W.W. Mumford and E. H. Scheibe, Horizon house, 1968, page 14

(See 2.2 Definition of Noise figure)

Therefore,

The **correct** noise figure equation, $F_i = 10 \cdot \log\left(1 + \frac{T_{e_i}}{290}\right)$ yields F_i

1.286
1.104
1.014
1.146

dB

Using this definition of the noise figure allows a comparison between noise figures measured on different test systems at different room temperatures, which is why this standard was originated to begin with.

Note that the effective noise temperature is not effected by this definition one way or another.

Appendix A:

Hot and Cold Load Noise Measurement Using Sky/Earth Temperature

A.0 Definition of Terms

T_h = earth temperature ^oK

T_c = sky temperature ^oK

P_h = output noise power with feed pointed at earth (earth temperature approx. 290 ^oK)

P_c = output noise power with feed pointed at sky (sky temperature approx. 5 ^oK)

Based on Microwave Remote Sensing Active and Passive, Volume 1, Microwave Remote Sensing Fundamentals and Radiometry, Fawwaz T. Ulaby, Richard K. Moore, Adrian K. Fung, Addison-Wesley Publishing Company, 1981, page 287

A.1 Example of Hot and Cold Noise Measurement Using Sky/Earth Temperature

$T_h := 290$ $\quad P_h := .986$ $\quad T_c := 5$ $\quad P_c := .131$ $\quad Y_{hc} := \frac{P_h}{P_c}$

$Y_{hc} = 7.527$

$T_e := \frac{T_h - Y_{hc} \cdot T_c}{Y_{hc} - 1}$ $\quad T_e = 38.667$ ^oK

$F := 10 \cdot \log\left(1 + \frac{T_e}{290}\right)$ $\quad F = 0.544$ dB